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DATA FUSION FOR NDE: WHAT, WHERE, WHY AND HOW

Claudia V. Kropas-Hughes, Ph.D.

Nondestructive Evaluation Branch (AFRL/MLLP)
Metals, Ceramics, and Nondestructive Evaluation Division
Materials and Manufacturing Directorate
Air Force Research Laboratory, Air Force Materiel Command
Wright-Patterson AFB, OH 45433-7750

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AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750

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Pamela M. Schaefer
Principal Materials Engineer
Technical & Strategic Planning Office
Materials and Manufacturing Directorate

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ABSTRACT *(Maximum 200 Words), ,*
Nondestructive Evaluation (NDE) is a systematic approach to detect flaws in parts. After detection, for a proper decision to be made about mitigation, the ***effect*** of that defect on the performance of the material is required. Therefore, the NDE of today, by necessity, *MUST* be more than just defect detection. The extrapolation of information from the NDE measurement or raw data is what the decision-maker of today needs to evaluate the material or system performance as a result of the presence of a defect. NDE is the only means to examine a material or component without destroying it, and therefore the primary input for evaluation of system performance. NDE provides a very powerful tool to assist decision making about parts serviceability.

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Claudia V. Kropas-Hughes, Ph.D.
Air Force Research Laboratory, Materials and Manufacturing Directorate
AFRL/MLLP
Wright-Patterson, Air Force Base, Ohio 45433
Tel: 937-255-9795
Fax: 937-255-9804
Claudia.Hughes@wpafb.af.mil

Abstract:

Nondestructive Evaluation (NDE) is a systematic approach to detect flaws in parts. After detection, for a proper decision to be made about mitigation, the ***effect*** of that defect on the performance of the material is required. Therefore, the NDE of today, by necessity, *MUST* be more than just defect detection. The extrapolation of information from the NDE measurement or raw data is what the decision-maker of today needs to evaluate the material or system performance as a result of the presence of a defect. NDE is the only means to examine a material or component without destroying it, and therefore the primary input for evaluation of system performance. NDE provides a very powerful tool to assist in efficient decision making about parts serviceability.

Keywords: nondestructive evaluation, data fusion, information processing

Introduction

NDE has traditionally been involved only with defect detection - finding flaws in materials. In point of fact, NDE is a systematic approach to detect flaws in parts. Though flaw detection is a necessary part of the process to ensure the system is capable of performing to necessary standards, the bare facts of a flaw and its location are not sufficient to today's decision makers. For a proper decision to be made, the identification of a defect is needed, and then the ***effect*** of that defect on the performance of the material is required to make an informed decision. The NDE of today, by necessity, *MUST* be more than just defect detection. In conjunction with the detection measurement, the raw data measurement must be correlated to the issues of interest in the inspection. In other words, the *INFORMATION* regarding the specific measurement must be obtained. This extrapolation of information from the NDE measurement or raw data is what the decision-maker of today needs to evaluate the material or system performance as a result of the presence of a defect. NDE is the only means to examine a material or component without destroying it, and therefore the primary input for evaluation of system performance.

What is data fusion for NDE?

The term data fusion is a true misnomer. The purpose of a nondestructive inspection is to verify that the material or component is in the expected configuration for its purpose, and therefore will perform as expected. The inspection provides

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measurements, which can be translated to defect present or not present. If the ultimate goal is to determine the performance capability of a component, then simply knowing the presence or absence of a defect is not sufficient to make that determination. More than a measurement is necessary to make the evaluation of system performance. This is accomplished through information, rather than data, with the possibility that additional measurements can provide and more reliable or complementary information. (Many sources exist to discuss a variety of aspects associated with data fusion. See General References.)

The concept of data fusion is integrally tied to the philosophy of knowledge management. Knowledge management is a process to understand how decision-makers make informed decisions. This concept includes the following algorithm for understanding [1]:

1. Data are discrete objective facts about event(s).
2. The message present in the raw data is the Contextual Information.
3. And Knowledge is derived from contextual information at the moment, along with experience, values, insight and many personal intangibles.

Therefore the correct terminology is not data fusion, but ***information fusion***.

For NDE, this information fusion starts with the inspection data obtained on a component. From the measurement data, the presence or absence of defects is one piece of information, but there is other information that oftentimes can be gleaned from the NDE data – other material properties associated with the material under examination. It is this conglomeration of pieces of information from a single NDE data set that can be fused to provide contextual information on the material. And multiple NDE techniques used to evaluate a component would most assuredly increase the amount of information available from the inspections.

Where is this data/information?

Every material has many physical properties that define its nature. Graphically, Figure 1 shows a representation of a space of properties represented by an arbitrary component.

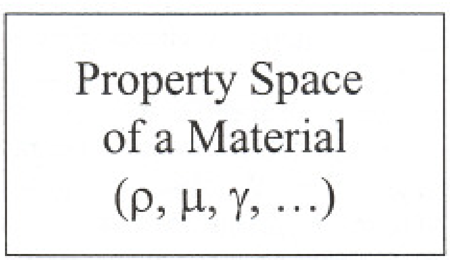

Figure 1. Graphical Representation of Material Property Space

Every NDE technique measures one or more of these properties, since each NDE method is a measurement of a physical phenomena reaction to specific material

properties. However, no one NDE method measures all properties, and typically each method measures only a limited set these properties.

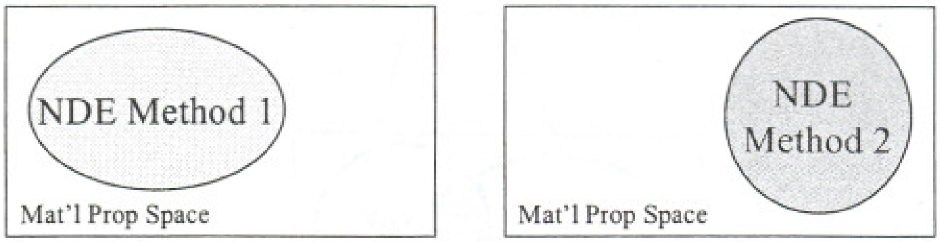

Figure 2. NDE Measurements of the Material Property Space

Each of the circles in the above Figure 2 represents the information about the material property space contained in that particular NDE examination. The information in any one of the NDE measurements is a subset of the total material property information space.

Why fuse information from multiple NDE methods?

Fusing information is only relevant after carefully identifying and determining the question to be answered – that is identifying a very focused problem space to be analyzed. What exactly is the ultimate decision to be made? From this question will come the context upon which the information must be determined. The specific context provides some additional understanding of the data needed by the inspection. So the first step in the analysis is to ask 2 questions: What decision is to be made? And what information is needed to make that decision?

Examination of the two questions will oftentimes show that the amount of information needed cannot be obtained from one data source - meaning that more than one data source will be necessary to gather the needed information to input into the knowledge base. This generates the need for information fusion of multiple NDE data sources.

Each of the circles in Figure 2 represents the information about the material property space contained in a particular NDE examination. The information in the NDE measurements is a subset of the total materials property information space. Overlap exists between methods (Figure 3.). Where multiple NDE technique fusion comes into play is the ability to take the information that is not in common between methods, and be able to supplement one method with information not present in the other method. Through fusion, information from one technique is able to complement another technique and provide a broader knowledge of the overall materials property space for the material or component under examination.

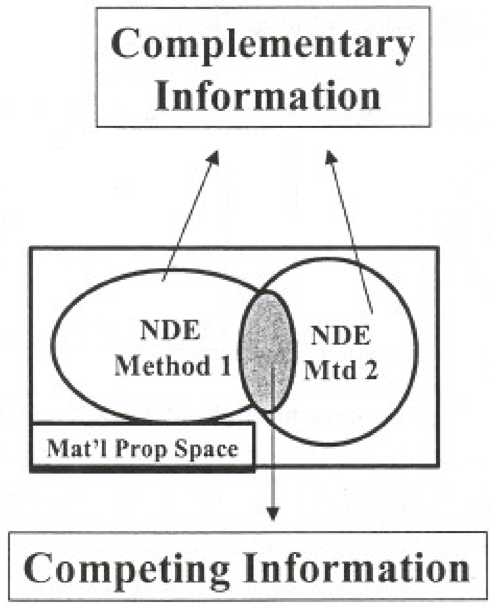

Figure 3. Complementary and Competing Information

Just as information not in common between NDE methods provides complementary information available for use, when two methods provide data for the same material property, this is referred to as competing information [2]. This is represented by the overlap area in Figure 3. Competing information has an additional burden associated with its analysis. Unless one of the methods is viewed as a "benchmark" measurement, then a computational combination of the multiple information sources can become extremely complicated. The potential does exist for combining the competing information to enhance a specific measurement for higher accuracy or reliability. This combining algorithm is the complicated aspect of utilizing the competing information. Many methods can be utilized depending on the problem being addressed. Competing information can be analyzed statistically or can be used to validate each of the methods for accuracy and reliability. The value of competing information analysis is dependent on the problem being addressed. For instance, verifying a flaw exists at a specific location is trivial if both NDE methods detect it; however, improving the dimensional accuracy of a flaw size by fusing multiple NDE measurement data is very difficult and complicated. Defect detection is verified with multiple NDE methods, but improving the NDE measurement (i.e. dimensional accuracy, precision, sizing, accuracy of measures, tolerances) is very tough to accomplish.

Figure 3 shows how powerful adding NDE techniques, and extracting the information, can be in the analysis of the entire spectrum of the material properties.

How to fuse information?

Humans can do it pretty automatically. Computationally, the computer can be programmed to extract features, then classify, using many, many recognized and studied pattern recognition techniques. Classifications that are well and analytically understood can be analyzed in mathematical closed form. If the actual relationships are not well

understood, then other methods such as statistical pattern recognition or neural networks can be employed.

Ultimately, information fusion is obtained by one of two basic approaches. Either determining the discriminating feature or parameter that is the information of interest from each NDE method, or defining a discriminating classification schema to process all the NDE data to a satisfactory result. The key to understanding the appropriate approach is to continually refine the problem space (i.e. Refine the question(s) being asked) and evaluate the NDE method to work within the problem space of interest. This analysis of the problem space can be thought of as a discovery process: a discovery of the understanding of what information is needed, and how to obtain the data that would provide the most information.

The use of this discovery process and refining the problem space, and then examining the characteristics of the NDE data to information potential, will determine which of the two possible approaches for the effort will be most likely. If the features of the data (that is, the parameters to provide the information) are well understood and accurately discriminate the issue of interest, then a simple classification scheme will suffice to provide the information of interest. If the features/parameter space is not well characterized, then a very accurate classification scheme will be necessary. Often times the problem reduces to a combination of both approaches. This means, if the features or parameter space is not completely and thoroughly understood, then the classification scheme to answer the problem, must be very discriminating on the features that are not completely accurate.

The feature extraction aspect is referred to in most pattern recognition problems as a pre-processing "transformation" of some sort, from which the discriminating, invariant features, that represent the parameters of interest in the problem space, are extracted from the raw data stream. This pre-processing task is typically selected for a particular application and requires very careful consideration to be an effective feature extraction device. Right now, there are no general rules on what is to be applied where and when for continual effectiveness.

There are two approaches to classification within a problem space. The first would be to determine the invariant, discriminating features applicable to the problem and use one classification scheme to fuse/combine the information. The second approach would be to generalize models for each of the NDE method, and use a classification scheme to combine only that information that is relevant to the question of the decision (Figure 4.). This second approach is ultimately moving the complicated process from defining the discriminating features, to an intricate classifier that must be able to wade through the complete NDE technique model and use only that information that is necessary for the information.

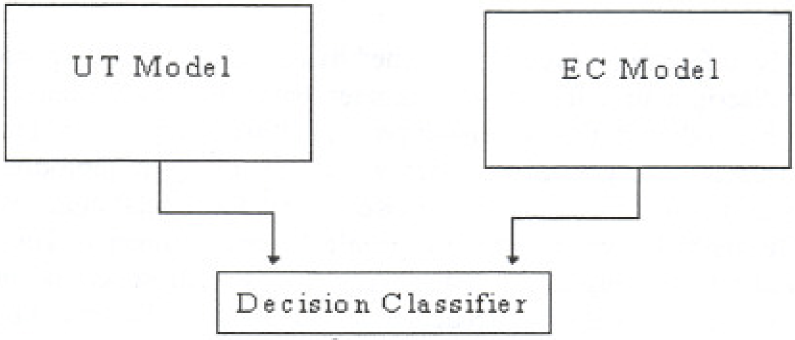

Figure 4. Representation of NDE Models and a Discriminating Classifier

In terms of the complementary and competing information spaces, the identification of features and the classification issues must be based on the problem being addressed. As represented in Figure 2, each NDE method represents a different topology in the materials property space. The overlap area represents features common to each NDE method. The complementary data are the features specific to each method. How the features are selected, whether competing or complimentary or both, depends on the question being asked and how broad a solution is required.

Conclusions

NDE has moved beyond its traditional role as a defect detection methodology. NDE, in conjunction with detection measurements, must provide a correlation between the measurement data to information necessary to assist in the analysis of the materials and components throughout useful service life. NDE provides a very powerful tool to assist in efficient decision-making.

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